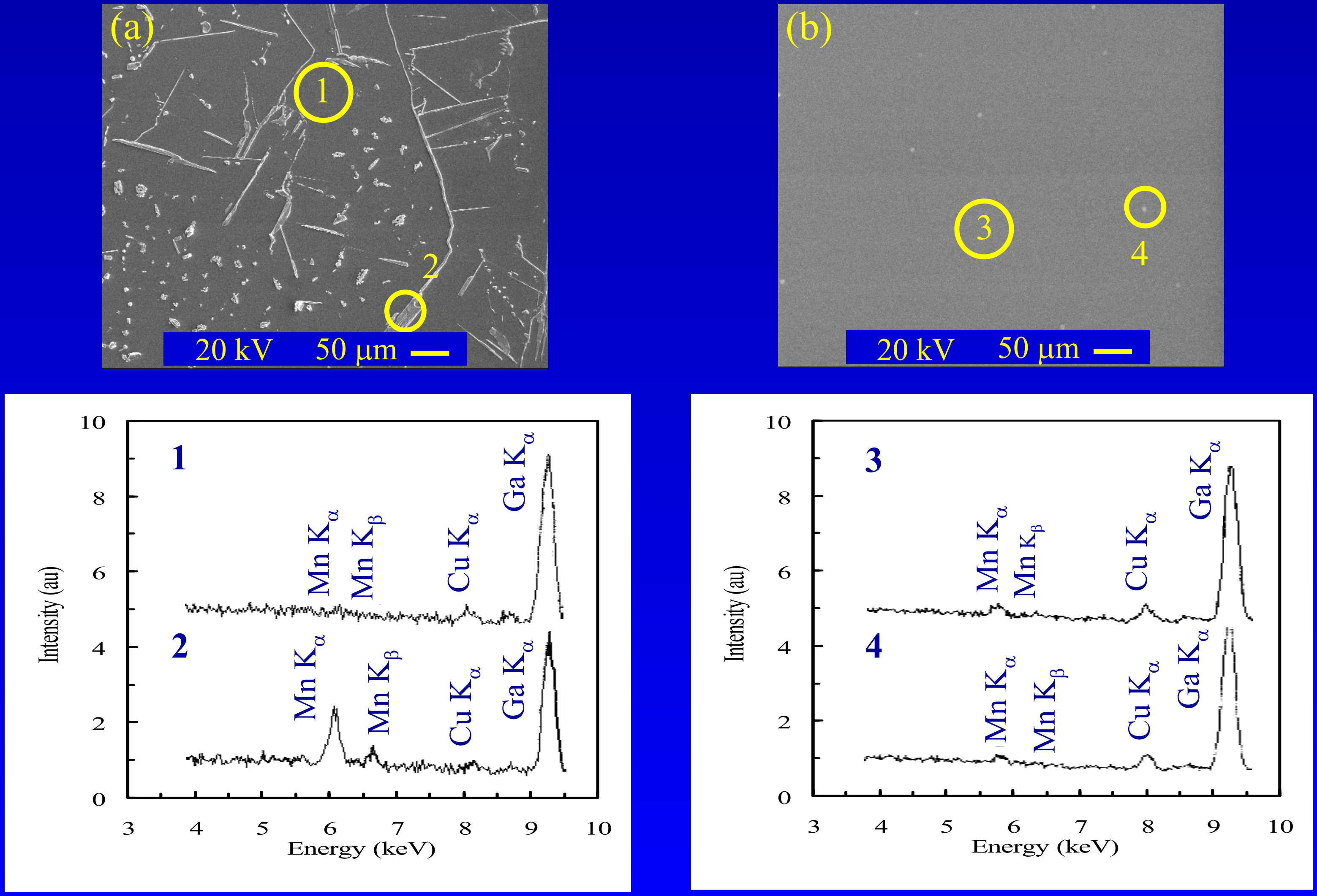
Molecular Beam Epitaxy of Spintronic Materials



Molecular Beam Epitaxy of Spintronic Materials; L. Li/U. Wis, Milwaukee; DMR-0094105 (NSF CAREER Award). The emerging field of spintronics is based on the use of electron ***spin*** in addition to charge to produce and process signals. This approach promises new functionality and higher performance at lower cost, as well as novel applications such as quantum computing. Ferromagnetic semiconductors (FMS), i.e. semiconductors that exhibit long-range ferromagnetic order when alloyed at the few percent level with a magnetic ion such as Mn, are promising materials for spin electronics, since they can both serve as an injector for spin polarized electrons, and can also be incorporated as active layers within complex heterostructures, an essential feature for more sophisticated spin device operation. However, epitaxial growth of FMS containing a few percent of magnetic ions has proven to be a formidable task due to secondary phase formation. Recently, we have discovered that hydrogen has strong influence on phase segregation during ECR plasma assisted MBE growth of GaMnN, and with optimized H_2/N_2 ratio secondary phases can be suppressed (Appl. Phys. Lett. **80**, 4139 (2002)). Shown in figure (a) is a SEM image of a film grown at 500 ^{o}C using N_2 plasma alone. The film surface is characterized by two distinct domains, as circled *1* and *2* in the figure. Domain *1* is featureless, and domain *2* consists of randomly distributed strips and clusters. In contrast, a featureless surface is obtained when H_2 is added to the N_2 plasma, as shown in figure (b). A few clusters are found scattered on the surface, one of them is circled and marked *4*. The bottom two panels show the composition of the films determined by energy dispersive spectroscopy (EDS). For films grown without the presence of hydrogen, no Mn was found in the featureless domain (spectrum *1*), while high concentrations of Mn (more than 40%) is found in the strips and clusters (spectrum *2*). Evidently, films grown with N_2 plasma alone have segregated into two phases, GaN and secondary phase containing Mn. Remarkably, films grown with the presence of hydrogen, a uniform 6.0% Mn concentration is found in the featureless domain (spectra *3*), slightly higher than the clusters (spectra *4*). X-ray diffraction has confirmed that films grown with N_2/H_2 plasma are single phase GaMnN. This demonstrates that $Ga_{1-x}Mn_xN$ with x as high as 0.06 can be grown by MBE using N_2/H_2 plasma.

Education Opportunities for Students at the Frontier of Spintronic Materials Research. Professor Li's research group at the University of Wisconsin, Milwaukee (UWM) (DMR-0094105, NSF CAREER Award) is engaged in the synthesis and characterization of magnetic semiconductors such as gallium manganese nitride (GaMnN) for spintronics. In addition to its outstanding research achievements, the group provides an excellent example of the opportunities its materials research had provided to a variety of levels of students. Supported by the NSF grant are: Yongjie Cui, Physics graduate student, who is also partially supported by a UWM Graduate School Dissertation Fellowship; Dr. Hongfei Liu, a postdoctoral researcher who received his Ph.D. from the Chinese Academy of Sciences, China, in 2001; Michael Lichtenberg, an undergraduate student from the Mechanical Engineering department, who is also partially funded by an UWM Advanced Analysis Facility Summer Internship; Kevin Quealy, an undergraduate student from the Physics Department, Gustavus Adolphus College, Minnesota, supported by the NSF Research Experience for Undergraduate (REU) program.

For practical applications, the Curie temperature (T_C) of any ferromagnetic semiconductor needs to be higher than 300 K. Currently, most experimental research has focused on GaMnAs and InMnAs. So far, the highest T_C achieved is 110 K for $Ga_{0.0947}Mn_{0.053}As$. This temperature is in good agreement with the predicted value of 120 K by a mean field theory. The same theory also predicts that $Ga_{1-x}Mn_xN$ (x=0.05) would have T_C higher than 300 K (see the attached figure). At the moment, we are investigating magnetic properties of our films, the findings will be reported soon. We don't quite understand the mechanism or role that H or H_2 plays in suppressing phase segregation. We suspect that they act as surfactant during growth, which might change surface energy and growth kinetics.

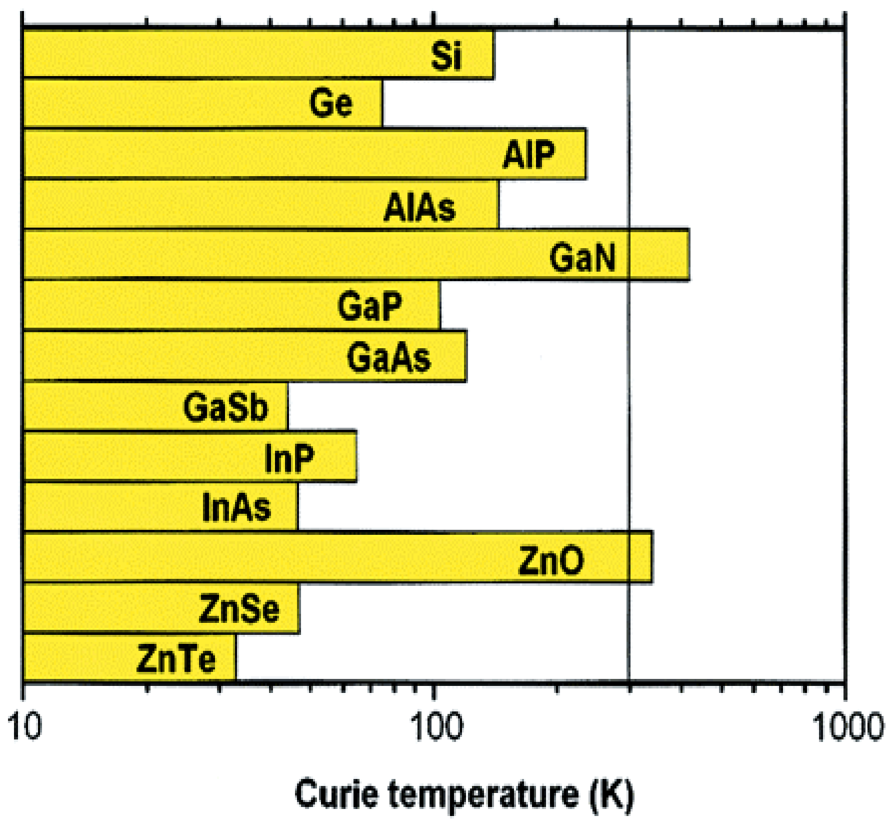


Fig. Calculated Curie temperature for various p-type semiconductors containing 5% of Mn (Dietl et al., Science 287, 1019 (2000).